Exotic searches in LHCb

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On behalf of the LHCb collaboration

Introduction & Content

- Multitude of exotic searches, complementary to general purpose detectors and b-factories, or unique in LHCb
- LHCb has many advantages:
  - low trigger thresholds and flexible software trigger
  - displaced vertex reconstruction *track IP resolution: 20μm for high-p_T tracks*
  - low pile-up *1.9 primary interactions per event*
  - particle identification
    - *muon ID efficiency: $\sim$ 97% for 1 $-$ 3% $\pi \to \mu$ mis-id probability*
    - *kaon ID efficiency: $\sim$ 95% for 5% $\pi \to K$ mis-id probability*

Content of this talk

- Lepton number violation: Majorana neutrinos in $B^- \to \pi^+ \mu^- \mu^-$
- Lepton flavour and baryon number violation in τ decays
- $H \to \tau\tau$
- Long-lived heavy exotic particles

Motivation

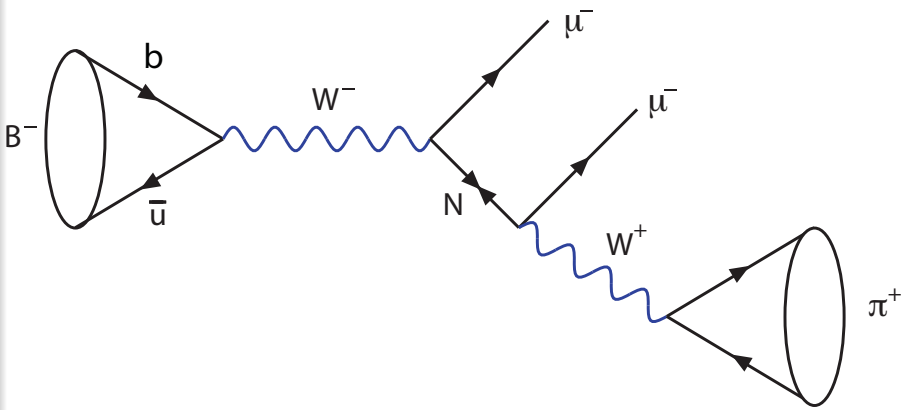
- Lepton flavour is conserved in standard model
- Neutrino oscillations imply that neutrinos are massive (not part of the SM), and therefore that lepton flavour conservation is violated
- Existence of Majorana neutrinos can be experimentally verified via lepton-number violating processes
- $B^- \to \pi^+\mu^-\mu^-$ is most sensitive B meson decay in the neutrino mass range up to 5 GeV [JHEP 05 (2009) 030]
  prior limits:
  - CLEO: $\mathcal{B}(B^- \to \pi^+\mu^-\mu^-) < 1400 \times 10^{-9}$ [Phys.Rev. D65 (2002) 111102]
  - Babar: $\mathcal{B}(B^- \to \pi^+\mu^-\mu^-) < 107 \times 10^{-9}$ [Phys.Rev. D85 (2012) 071103]
  - LHCb (0.41fb^{-1}): $\mathcal{B}(B^- \to \pi^+\mu^-\mu^-) < 13 \times 10^{-9}$ [Phys.Rev. D85 (2012) 112004]

LHCb ANALYSIS [PHYS.REV.LETT. 112 (2014) 131802]

- 3 fb^{-1} of data collected in 2011 and 2012 at $\sqrt{s} = 7$ and 8 TeV
- Measure $\mathcal{B}(B^- \to \pi^+\mu^-\mu^-)$ for neutrinos with a lifetime up to 1 ns

EVENT SELECTION

- Hardware trigger on μ or di-μ ($p_T > 1.64$ GeV)
- Software trigger on vertex with μ and tracks displaced from primary interaction
- Different selections for short-lived (< 1ps) and long-lived (< 1ns) neutrino, separating the ($\pi\mu$) neutrino decay vertex from the B^-
- Selection efficiency varies as a function of the neutrino mass and lifetime



[Phys.Rev.Lett. 112 (2014) 131802]

Extract signal events

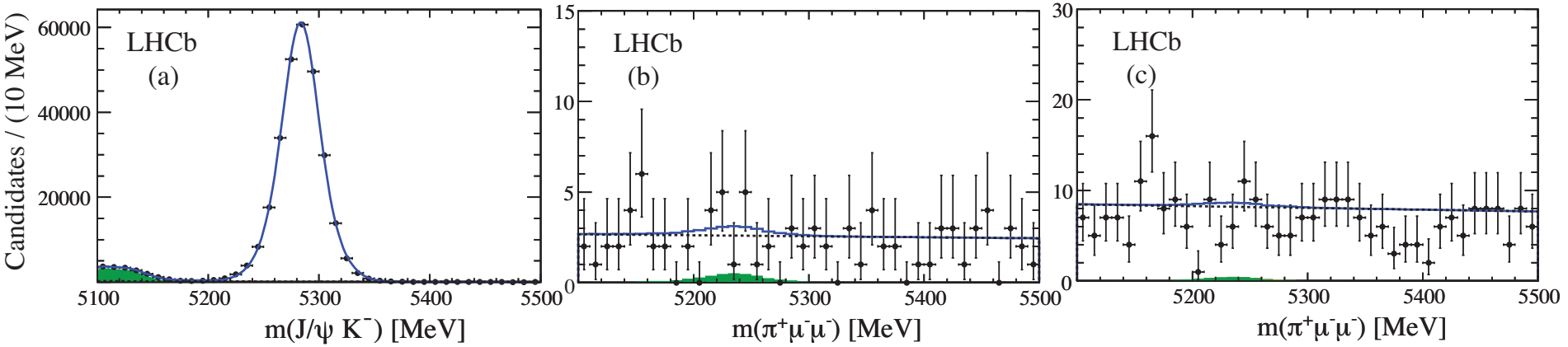
- Backgrounds (e.g. $J/\psi K^-$,$J/\psi \pi^-$) :
  - B^- to charmonium (peaking background shown in green)
  - combinatoric (dotted line)

normalisation channel

$B^- \to J/\psi(\mu^+\mu^-)K^-$

short lifetime ($<$ 1ps)

long lifetime ($<$ 1ns)



Extract neutrino candidates

- Select events in B^- mass window ($\pm 2\sigma$)
- No signal events observed after background subtraction

[Phys.Rev.Lett. 112 (2014) 131802]

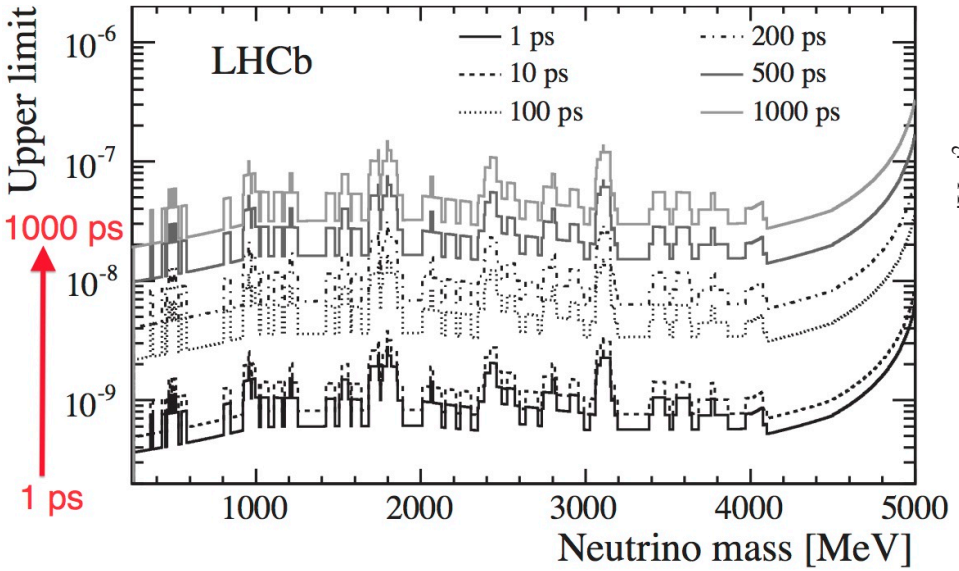
- Model-independent upper limit as function of neutrino mass, for various lifetimes

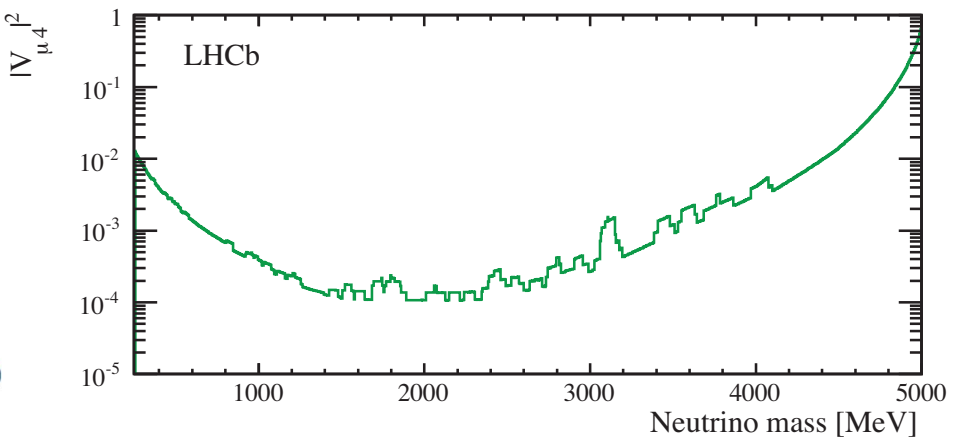
CLs upper limit on branching fraction

$\mathcal{B}(B^- \to \pi^+\mu^-\mu^-) < 4.0 \times 10^{-9}$ at 95% CL (for $\tau_N \lesssim 1$ ps)

$\to$ current best limit

- Branching ratio normalised to $B^- \to J/\psi(\mu^+\mu^-)K^-$
- Translated into model-dependent upper limit on $|V_{\mu 4}|^2$ [JHEP 05 (2009) 030]

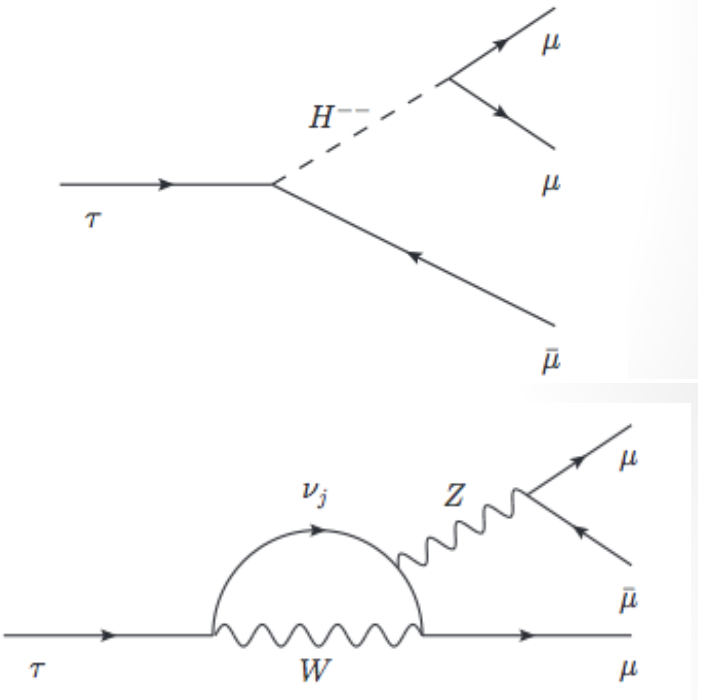




[Phys.Rev.Lett. 112 (2014) 131802]

LFV and BNV in τ decays

- LFV forbidden in SM, but neutrino oscillations allow it in loops, at $\mathcal{B} < 10^{-40}$
- Can be enhanced by new physics (e.g. models with doubly charged Higgs, or heavy particles in the loop)

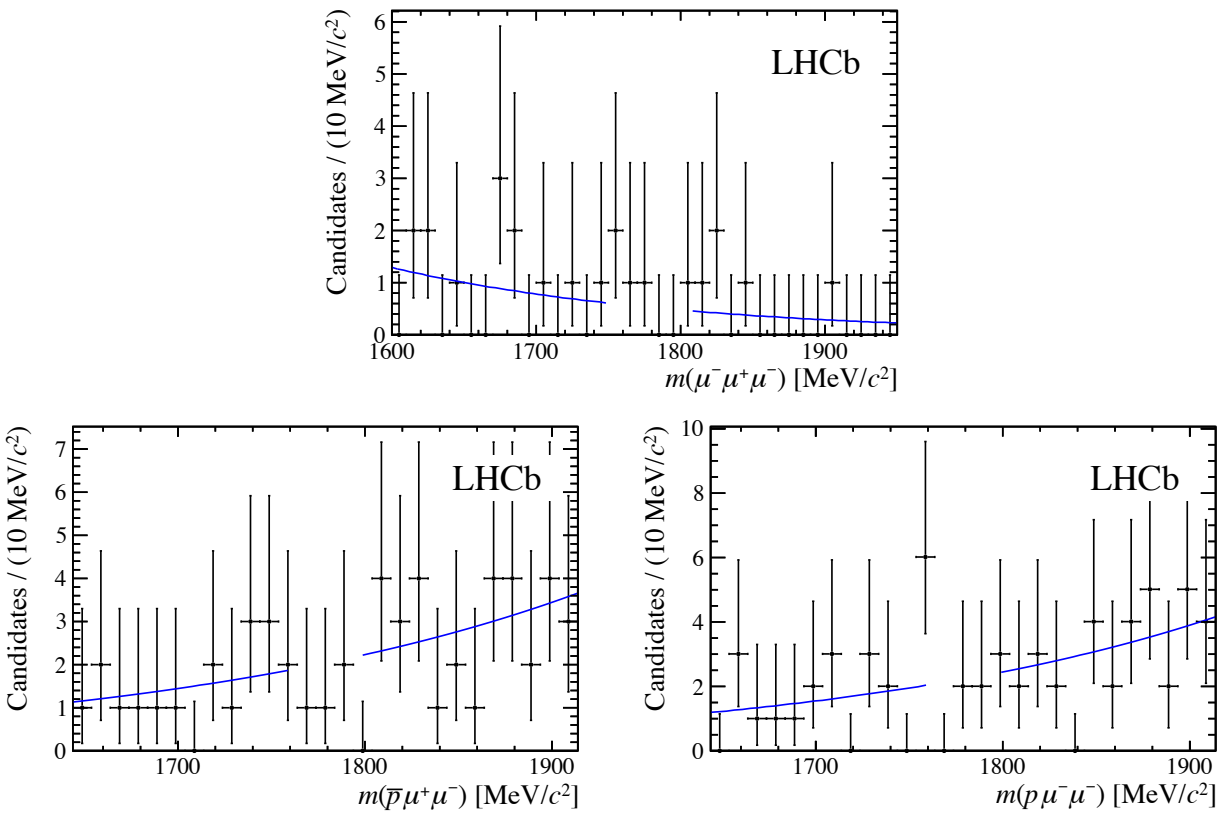


LHCb analysis [Phys.Lett. B724 (2013) 36-45]

- 1 fb^{-1} of data collected in 2011 at $\sqrt{s} = 7$ TeV
- Search for lepton flavour and baryon number violation in:
  - $\tau^- \to \mu^-\mu^-\mu^+$ (LFV)
  - $\tau^- \to \bar{p}\mu^-\mu^+$ (LFV, BNV)
  - $\tau^- \to p\mu^-\mu^-$ (LFV, BNV)

[Phys.Lett. B724 (2013) 36-45]

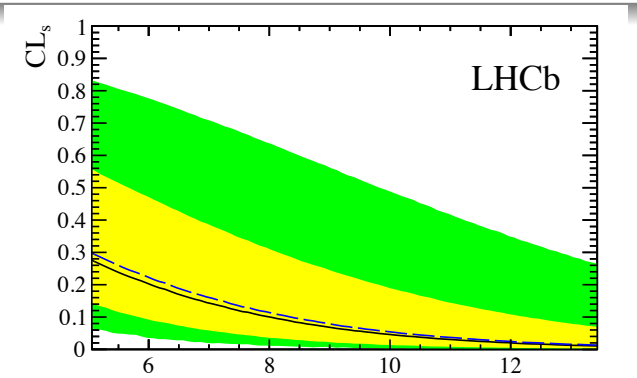
- Calibration channel: $D_s^- \to \phi(\mu^+\mu^-)\pi^-$
- Signal-background separation using likelihoods for decay topology, particle identification, τ mass
- Mass distribution in likelihood bins with highest signal probability
- Number of observed events compatible with background expectation

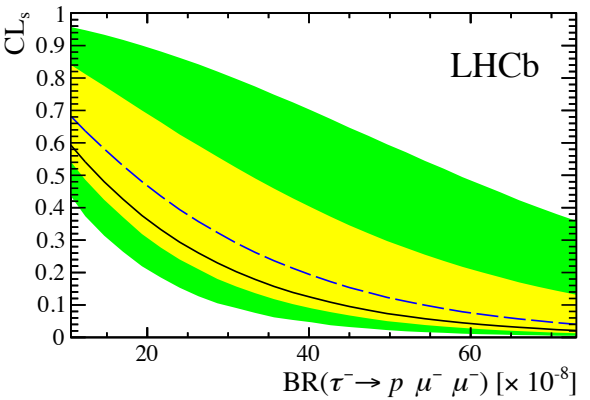


[Phys.Lett. B724 (2013) 36-45]

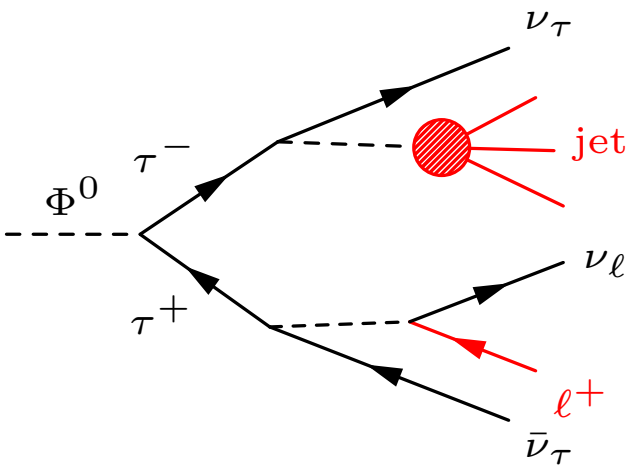
CLs observed upper limits at 90% (95%) CL

- $\mathcal{B}(\tau^- \to \mu^-\mu^-\mu^+) < 8.0\ (9.8) \times 10^{-8}$
  $\to$ first result at hadron collider, compatible with results from
  - Babar: $< 3.3 \times 10^{-8}$ at 90% CL [Phys.Rev. D81 (2010) 111101]
  - Belle: $< 2.1 \times 10^{-8}$ at 90% CL [Phys.Lett. B687 (2010) 139-143]
- $\mathcal{B}(\tau^- \to \bar{p}\mu^-\mu^+) < 3.3\ (4.3) \times 10^{-7}$ $\to$ first result
- $\mathcal{B}(\tau^- \to p\mu^-\mu^-) < 4.4\ (5.7) \times 10^{-7}$ $\to$ first result



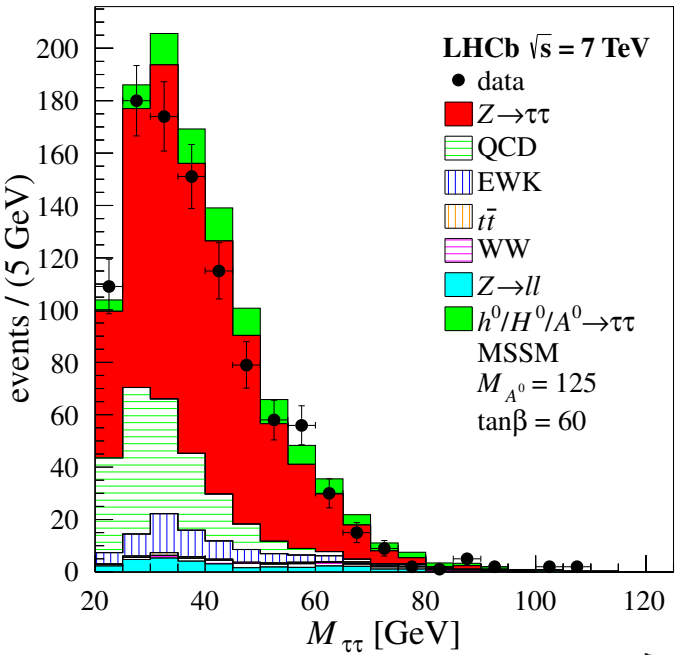


[Phys.Lett. B724 (2013) 36-45]



LHCb ANALYSIS [JHEP 1305 (2013) 1325]

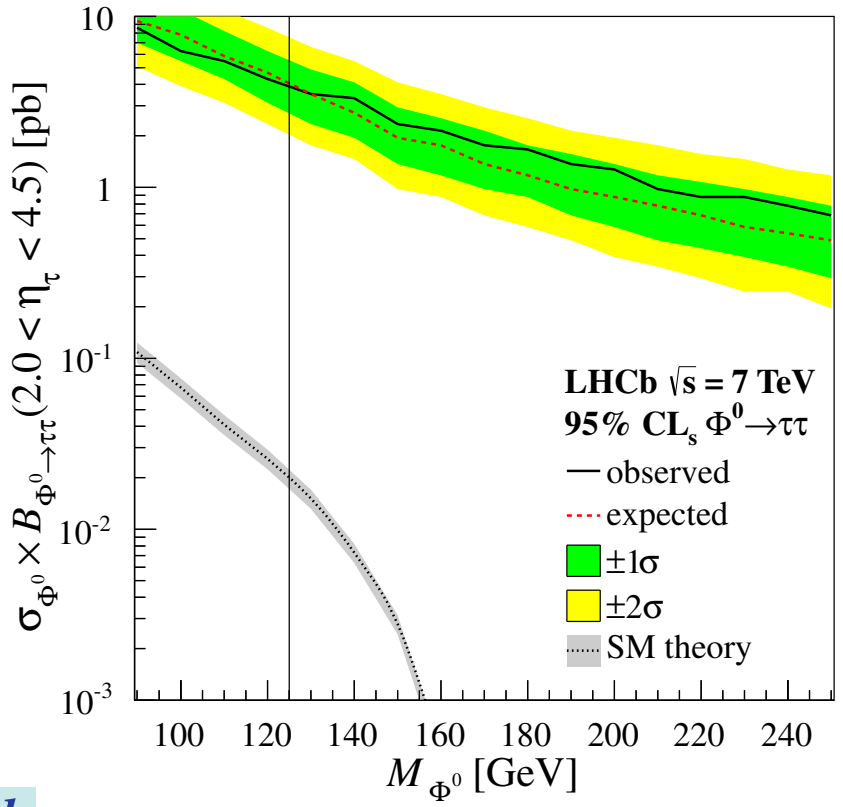
- 1 fb^{-1} of data collected in 2011 at $\sqrt{s} = 7$ TeV
- Search for a neutral Higgs (either SM or non-SM) decaying to final states:
  - $\mu\mu, \mu e, \mu h, eh$
- Extension of $Z \to \tau\tau$ cross-section measurement

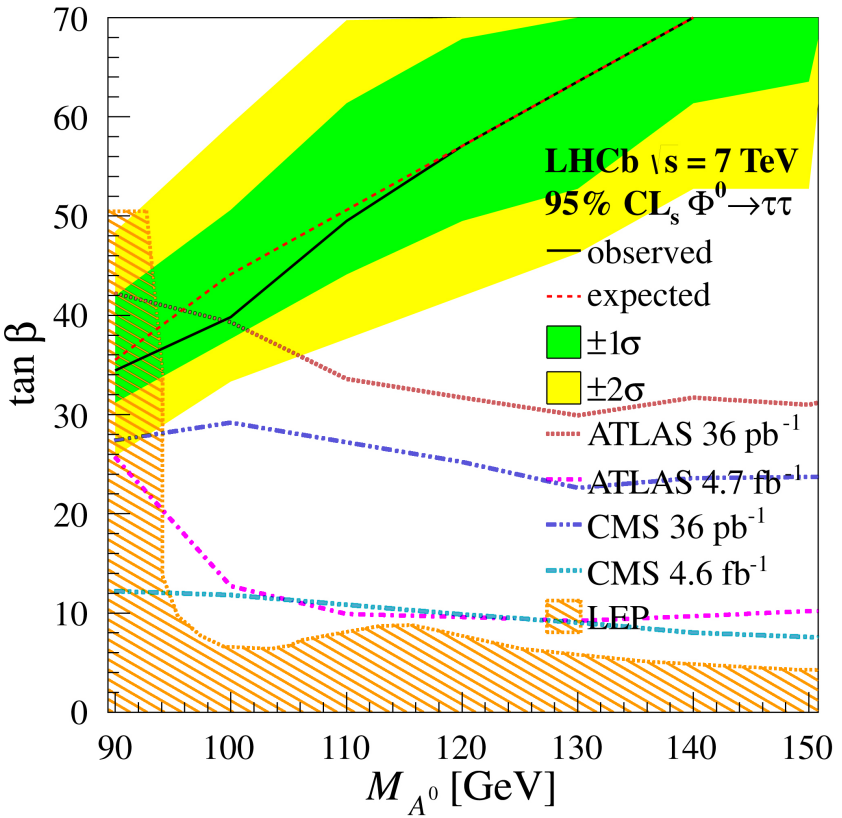


[JHEP 1305 (2013) 1325]

CLs observed upper limit at 95% CL

- Model-independent upper limit on SM Higgs to $\tau\tau$
- Model-dependent upper limit on tan β in MSSM, compared to ATLAS [Phys. Lett. B705 (2011) 174][JHEP 02 (2013) 095], CMS [Phys. Rev. Lett. 106 (2011) 231801] [Phys. Lett. B713 (2012) 68] and LEP [Eur. Phys. J. C47 (2006) 547]





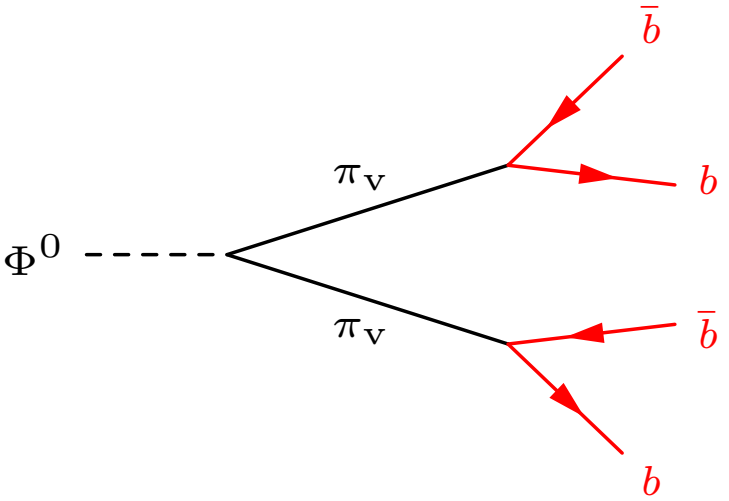
[JHEP 1305 (2013) 1325]

Long-lived heavy exotic particles

Various new-physics models (Hidden Valley [Phys. Lett. B651 (2007) 374], mSUGRA [Phys.Rev.Lett. 99 (2007) 211801], etc.) predict heavy exotic metastable particles

LHCb analysis [LHCB-CONF-2012-014]

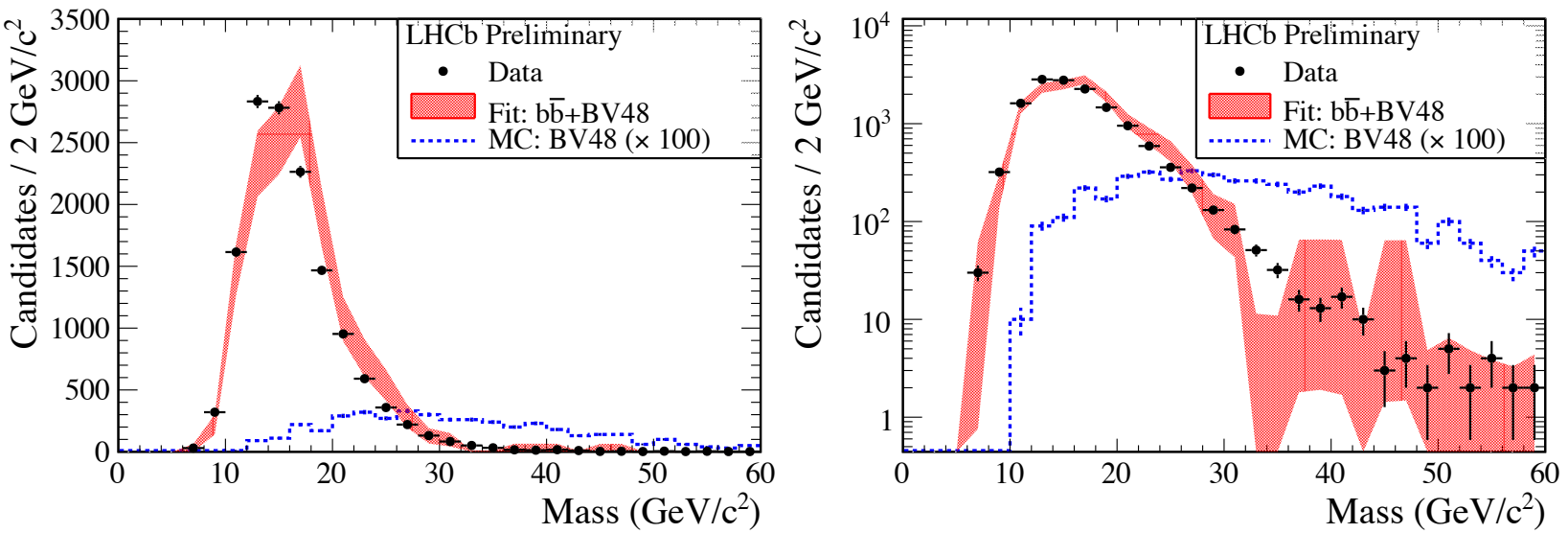
- 39 pb^{-1} of data collected in 2010 at $\sqrt{s} = 7$ TeV
- Search for a Higgs decaying to unknown scalars (π_v, neutralino χ_1^0, ...), which decay into SM particles (mainly $b\bar{b}$)
- Require two displaced vertices, with mass > 6 GeV and ≥ 6 tracks



[LHCB-CONF-2012-014]

To be updated soon with 1fb^{-1}

Candidate pairs are consistent with $b\bar{b}$ background (39 pb^{-1}) :



- Requiring minimal $\Delta\phi$ between the candidates removes all events

[LHCB-CONF-2012-014]

95% CL upper limit

$\mathcal{B}(h^0 \to \chi_1^0 \chi_1^0) < 32$ pb
(for $m_{\chi_1^0} = 48$ GeV, $\tau_{\chi_1^0} = 10$ ps, $m_{h^0} = 114$ GeV)

- ATLAS: limits for longer lifetimes ($\tau_{\chi_1^0} > 1.5$ ns), using muons [Phys. Rev. Lett. 108 (2012) 251801
- CMS: limits for higher masses ($m_{\chi_1^0} > 50$ GeV and $m_{h^0} > 200$ GeV) [PoS EPS-HEP2013 (2014) 307]

- LHCb has a unique phase-space, at low mass and low lifetime
- Upper limit between 29-179 pb, set for masses between 20-48 GeV, lifetimes between 5-15 ps
- Soon update with 1fb^{-1}, searching for individual long-lived partices decaying into *b*-jets

Summary

95% CL upper limits on:

- Lepton number violating decay probing Majorana neutrinos:
  - $\mathcal{B}(B^- \to \pi^+ \mu^- \mu^-) < 4.0 \times 10^{-9}$ (for neutrino lifetime $\lesssim$ 1 ps) $\to$ current best limit
- Lepton flavour violation in τ decays:
  - $\mathcal{B}(\tau^- \to \mu^- \mu^- \mu^+) < 9.8 \times 10^{-8}$ $\to$ first result at hadron collider
- Baryon number violation in τ decays :
  - $\mathcal{B}(\tau^- \to \bar{p} \mu^- \mu^+) < 4.3 \times 10^{-7}$ $\to$ first result
  - $\mathcal{B}(\tau^- \to p \mu^- \mu^-) < 5.7 \times 10^{-7}$ $\to$ first result
- Higgs decay to $\tau\tau$
  - SM Higgs to $\tau\tau$: 8.6 - 0.7 pb (for $m_H = 90 - 250$ GeV)
  - tan β in MSSM: 34 - 70 (for $m_H = 90 - 140$ GeV)
- Higgs decay to long-lived particles:
  - $\mathcal{B}(h^0 \to \chi_1^0 \chi_1^0) < 32$ pb (for $m_{\chi_1^0} = 48$ GeV, $\tau_{\chi_1^0} = 10$ ps, $m_{h^0} = 114$ GeV)
    $\to$ unique phase-space

Conclusion

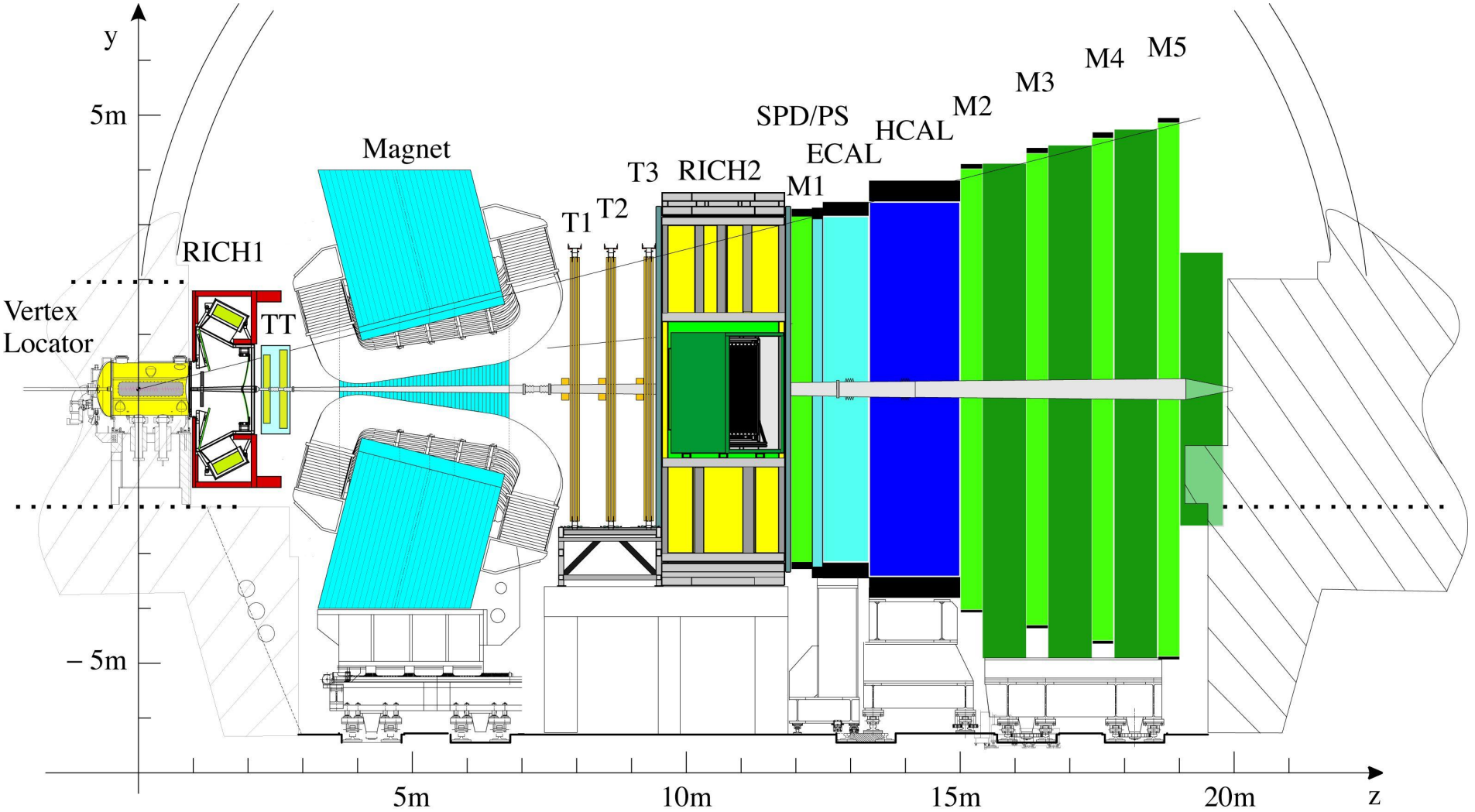
- Multitude of exotic searches, complementary to general purpose detectors and b-factories, or unique in LHCb

Outlook

- Updates for 2011 and 2012 data underway
  - Increased luminosity
  - Improved or new analyses (e.g. long-lived stau, long-lived particle decaying to jets)
- Looking forward to a larger data set and higher beam energy

Backup

LHCb DETECTOR

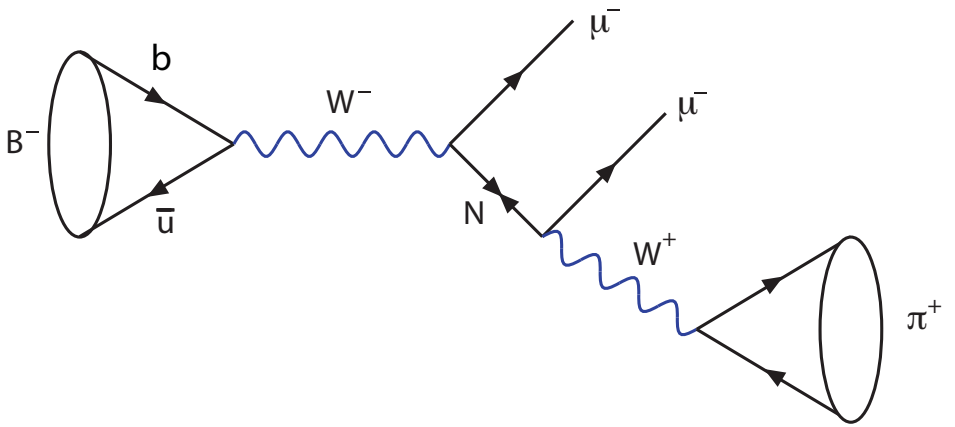


Common Selection

- Hardware trigger on μ or di-μ ($p_T > 1.64$ GeV)
- Software trigger on vertex with μ and tracks displaced from primary interaction
- Offline selection:
  - μ with $p > 3$ GeV, $p_T > 0.75$ GeV
  - π with $p > 2$ GeV, $p_T > 1.1$ GeV
  - B^- should point to the primary interaction

Lifetime-specific Selection

- short-lived neutrino:
  - vertex $(\mu\mu\pi)$ $\chi^2 < 4$
- long-lived neutrino:
  - p_T $(\mu\pi) > 0.7$ GeV
  - vertex $(\mu\pi)$ $\chi^2 < 10$
  - vertex (μ) $(\mu\pi)$ $\chi^2 < 4$
  - neutrino $(\mu\pi)$ should not point to primary interaction



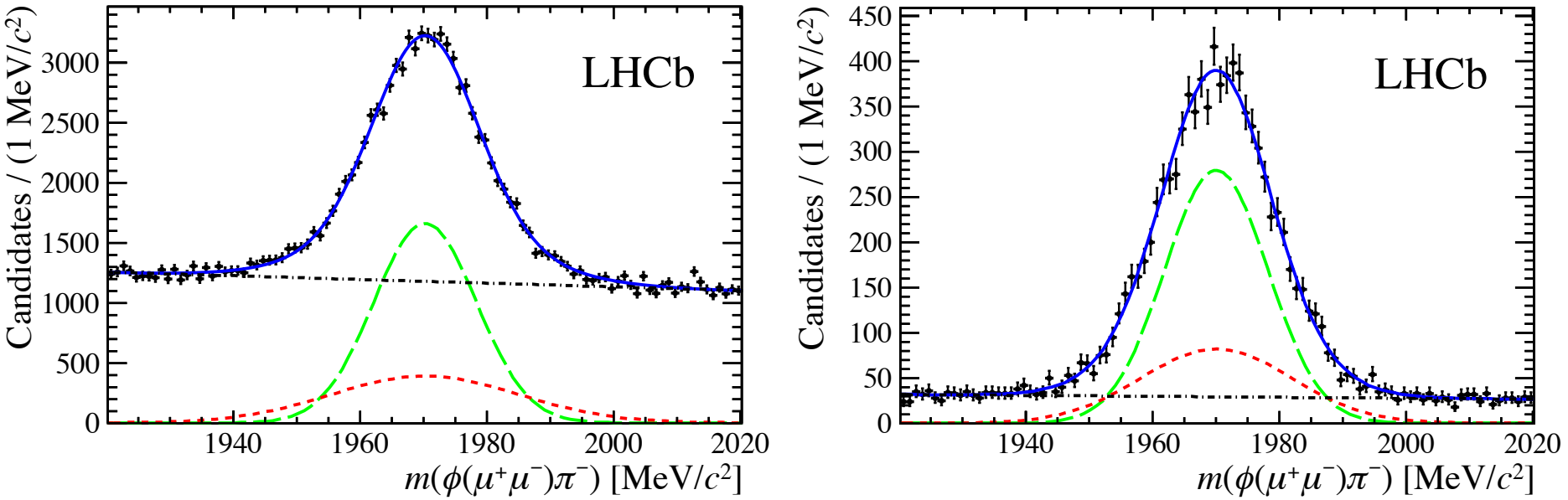


FIGURE 1 : Invariant mass distribution of the calibration channel $\phi(\mu^+\mu^-)\pi^-$ after (a) the $\tau^- \to \mu^-\mu^+\mu^-$ selection and (b) the $\tau \to p\mu\mu$ selection and PID cuts. The solid (blue) lines show the overall fits, the long dashed (green) and short dashed (red) lines show the two Gaussian components of the signal and the dot dashed (black) lines show the backgrounds.